Scientific questions to be addressed with a coupled climate-ice sheet model

Miren Vizcaíno

Department of Geography and Berkeley Atmospheric Science Center,
University of California, Berkeley, USA

Previously: Max Planck Institute for Meteorology, Hamburg, Germany

Ice sheets shape climate

- Many studies have treated ice sheets as passive components for projections of future sea level change
- But ice sheets can modify climate via modifications of
  - Freshwater fluxes => affecting MOC
  - Topographic height
    - Dynamical effect
    - Thermodynamical effect
  - Albedo
    - Ice retreat
    - Change of ice sheet albedo (meltwater, impurities)

- Additionally, modifications of local climate by ice sheets might be important for the mass balance budget: how much, in which situation, and at which stage?

Outline

Coupled ice sheet- AOGCMs

Results of studies investigating climate modification by changes in ice sheets and its effect on ice sheet mass balance

1. Effect of Greenland on the MOC
2. Topographic effect on atmospheric circulation
3. Thermodynamic effect of height change
4. Albedo change

Reversibility of deglaciation?

Implications for modeling

Existent coupled ice sheet - AOGCM studies

- Hadley Center Model: (ice sheet model from Ph. Huybrechts, SIA)
  - Ridley et al. 2005: in AR4 IPCC
- Max Planck Institute for Met., Hamburg: (ice sheet model SICOPOLIS, R. Greve; SIA)
  - (Vizcaíno et al 2008; Mikolajewicz et al., CD, 2007) with echam3/lsg
  - (Vizcaíno et al in review; Mikolajewicz et al., GRL, 2007) with echam5/mpi-om

    surface mass balance: energy balance, uncorrected forcing

<u>Bidirectional coupling</u>

Ice sheet model passes to

- atmosphere: topography, glacier mask
- ocean: freshwater fluxes

Outline

1. **Effect of Greenland on the MOC**
2. Topographic effect on atmospheric circulation
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Overview of studies

C=collapse, W=weakening

Study	Type of model	Input	**C**	**W**
Fichefet et al. 2003	Coupled AOGCM-ism, fixed top		Yes	
Driesschaert et al. 2007	coupled emic-ism	Up to 0.1 Sv	No	Yes
Ridley et al. 2005	Coupled AOGCM-ism			Yes
Vizcaino et al. 2008	“	Up to 0.02 Sv	No	No
Mikolajewicz et al. 2007	“	0.02 Sv	No	Yes

Antarctica?

Meltwater water from AIS can strengthen AMOC *(Mikolajewicz, 1998)*

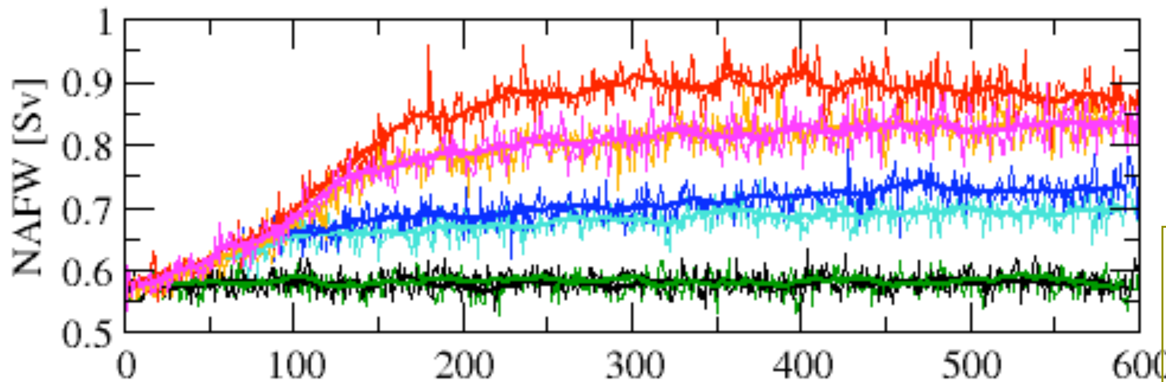
Greenland melt prevents recovery

- no role of meltwater on initial weakening, but on restablishement *(Mikolajewicz et al. 2007)*

Net freshwater fluxes into North Atlantic and Arctic [Sv]
(precip-evaporation over ocean + river run-off + melt ice sheets)

Interactive:
CTRL
2xCO2
4xCO2

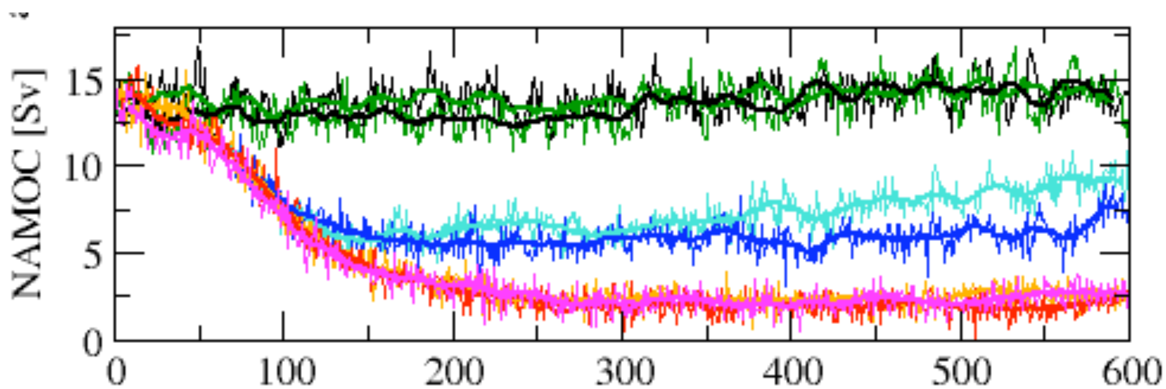
Passive:
CTRL
2xCO2
4xCO2
4xCO2



} red-pink = greenland melt

(Max. from ice sheets: **0.1 Sv and 0.02 Sv)**

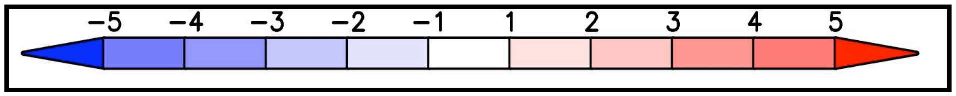
Maximum of MOC [Sv]



MOC changes and Greenland melt (case 1)

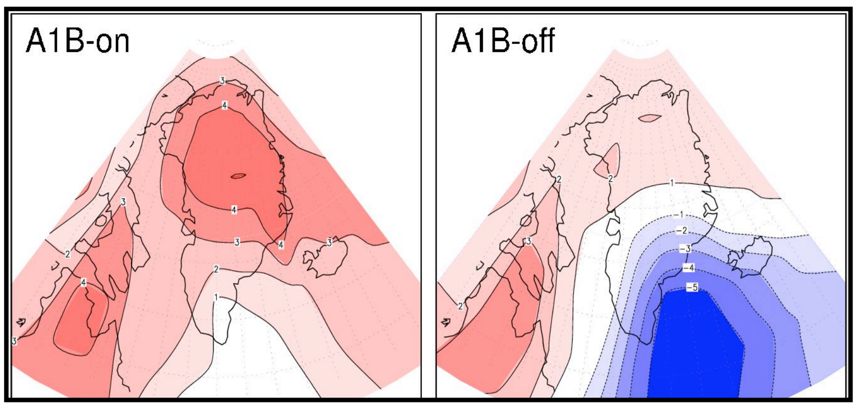
- If MOC weakening causes regional cooling over Greenland, this would reduce melting rates drastically

(Mikolajewicz et al. 2007)

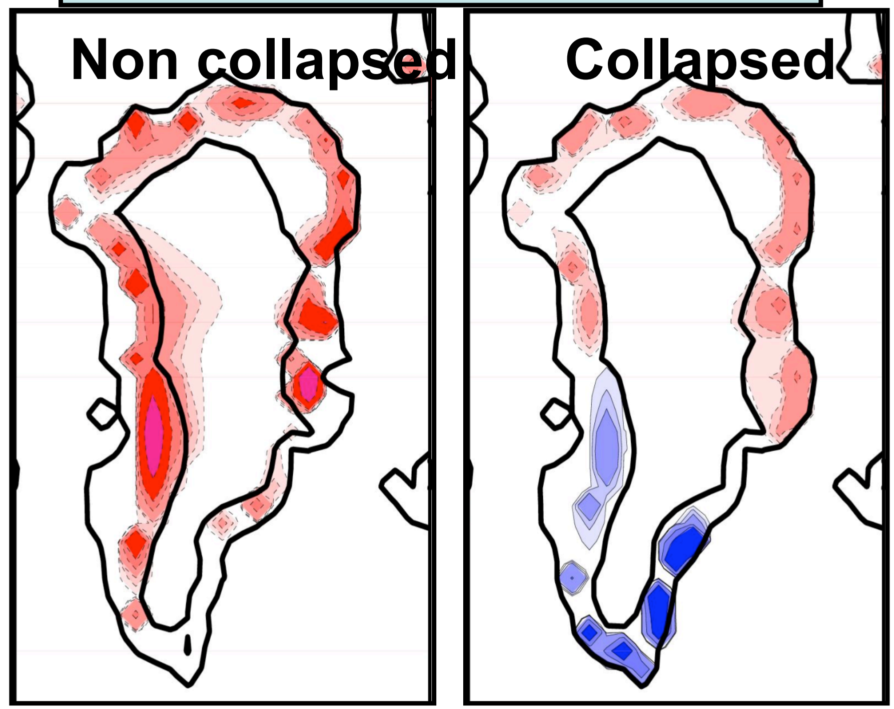


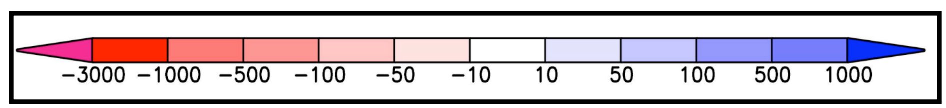
temperature [K]

Non collapsed **Collapsed**



Melting change wrt pre-industrial [mm yr-1]





Ice loss

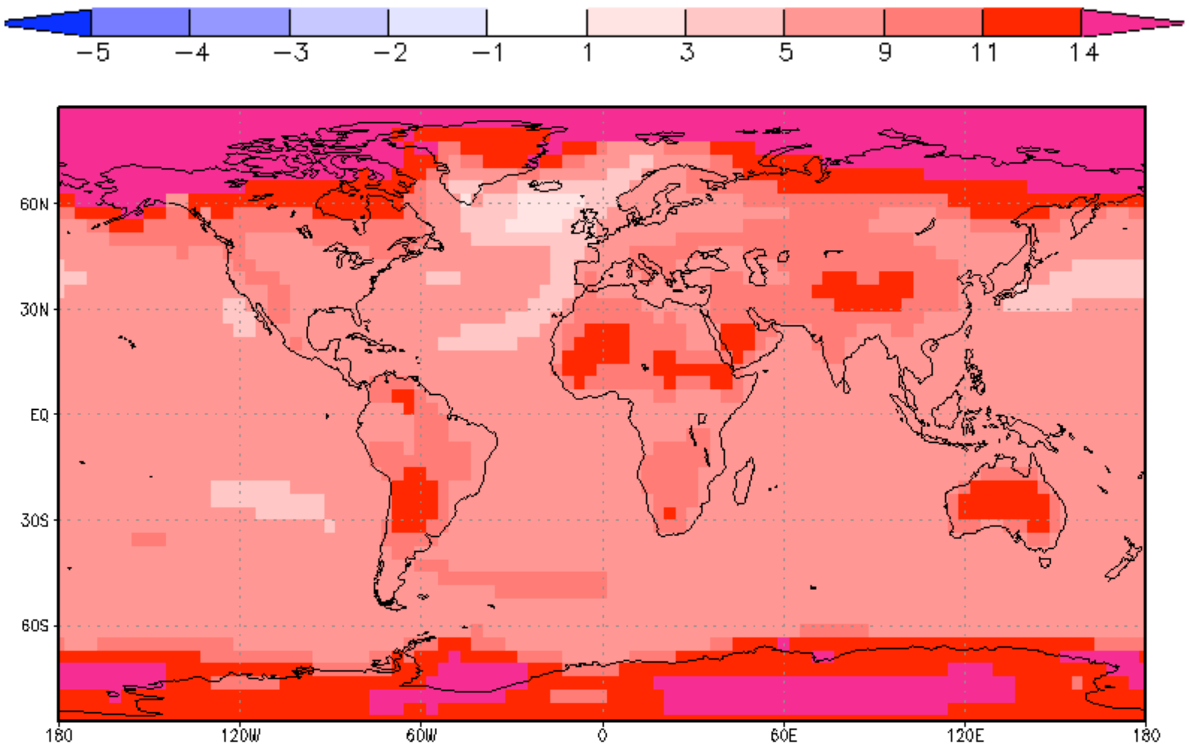
Ice gain

Possibility of negative feedback?

MOC changes and Greenland melt (case 2)

- Alternative scenario: collapse of the MOC ameliorate the warming over Greenland, but produce no cooling

Annual temperature change [K] in 4xCO2 simulation with collapsed MOC



(figure from Vizcaino et al. in review)

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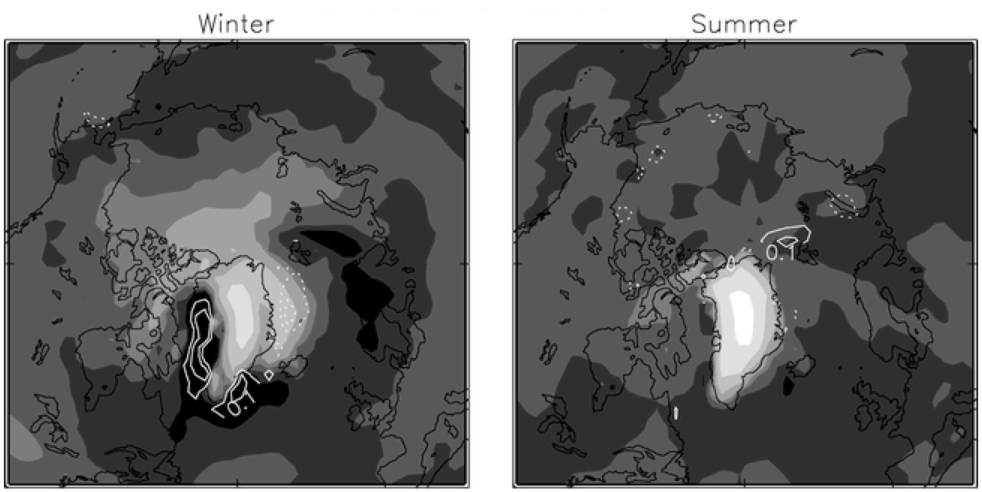
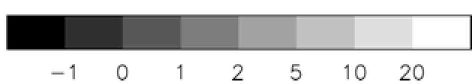
Effect of deglaciation on mean circulation

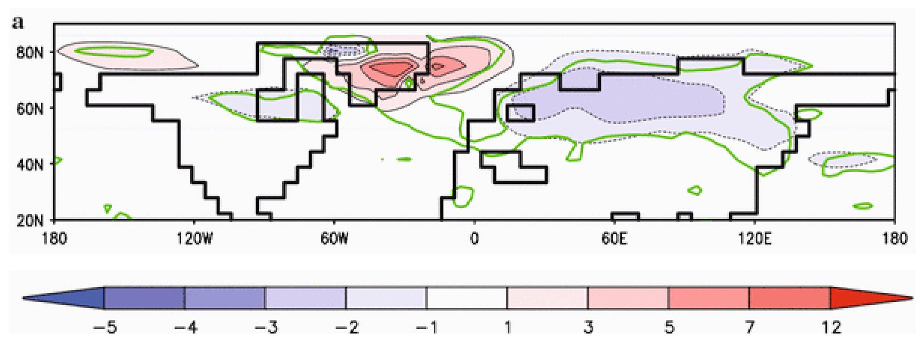
- Total deglaciation of Greenland produces a more zonal flow
- This cools Scandinavia and Barents Sea, mainly in winter
  (Junge et al. 2004; Toniazzo et al. 2004; Ridley et al. 2005; Vizcaino et al. 2008)
- Dependency of circulation changes on model resolution (Junge et al. 2004)

Temperature change



Toniazzo et al. 2004



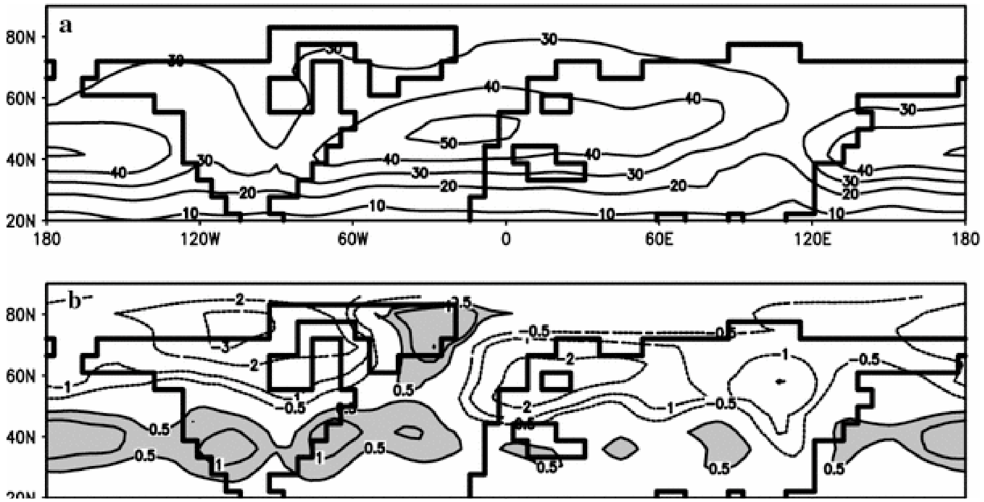


Vizcaino et al. 2008

Effect of deglaciation on storm-track

- Storm-track increases over Greenland

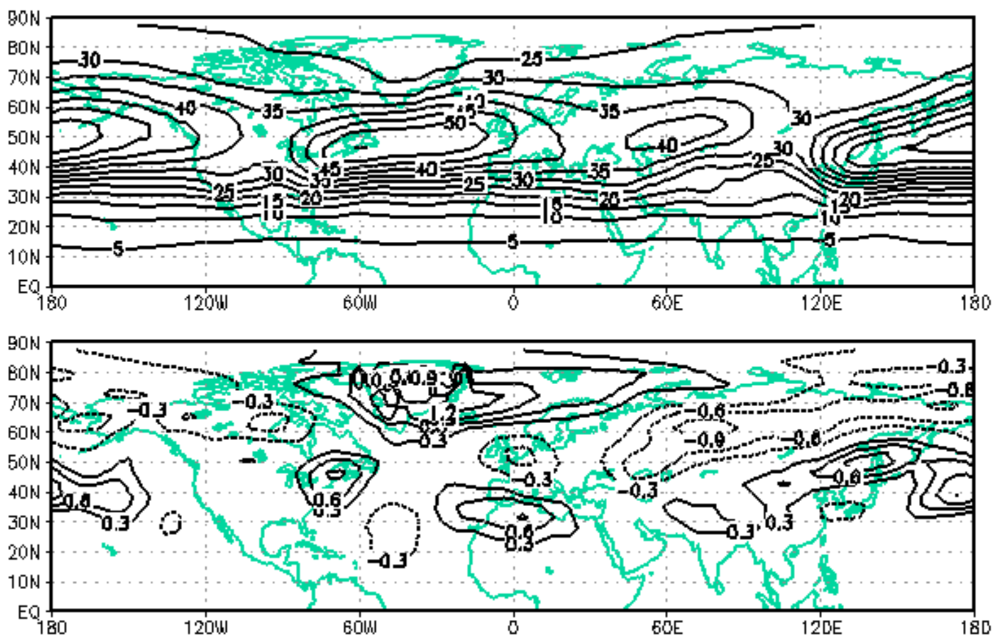
Standard deviation of 500-hPa geopotential height, 2.5-6 days bandpass [gpm]



Reference state

Effect of total deglaciation

(Vizcaino et al. 2008)



Reference state

Effect of partial (1/3 volume) deglaciation

(Vizcaino et al. in review)

Outline

1. Effect of Greenland on the MOC
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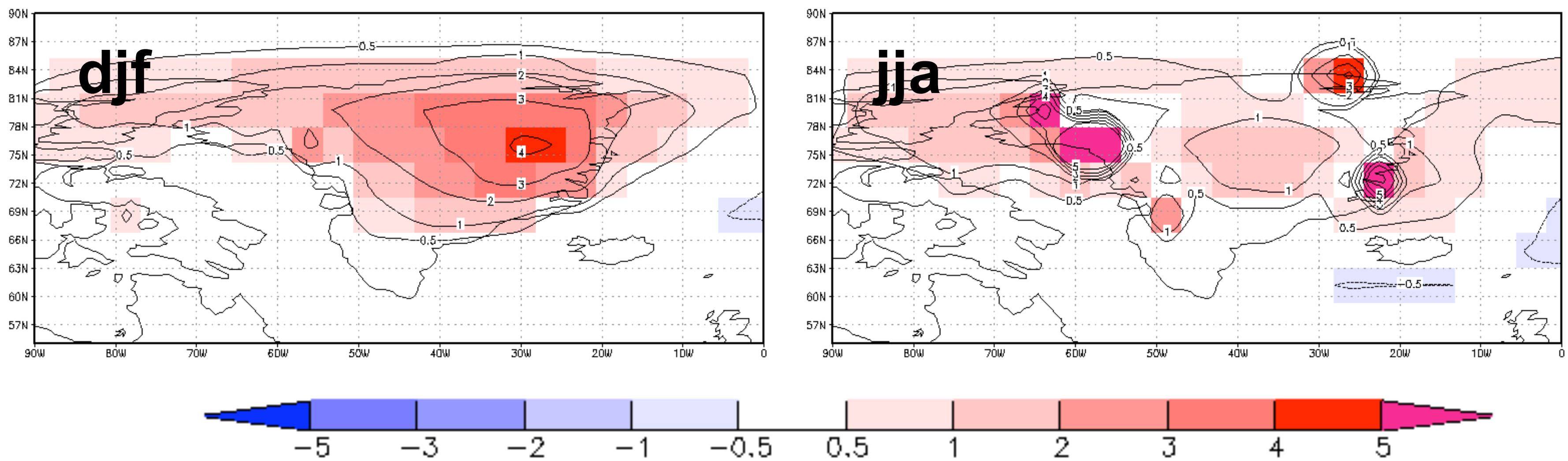
Thermodynamical effects of height changes

- Positive feedback for melting
- Magnitude: ~ 6.5 K per km => ~ +13 K for Greenland deglaciation

Limited summer warming with partial deglaciation if surface is at melting point *(Vizcaino et al. in review)*



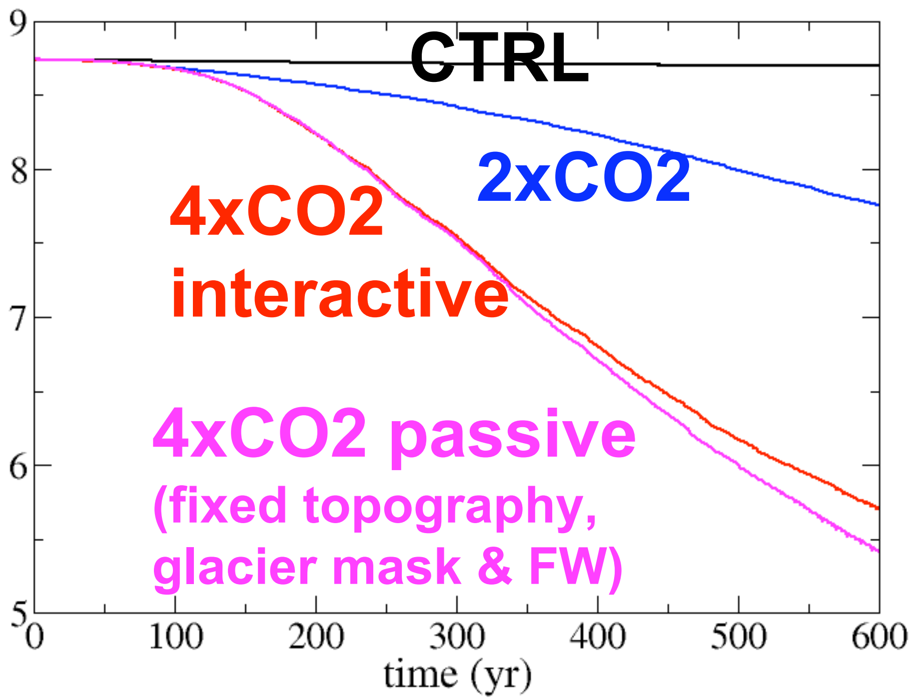
Temperature change [K]

Overestimation of melt rates in off-line studies?

(Vizcaino et al. in review)

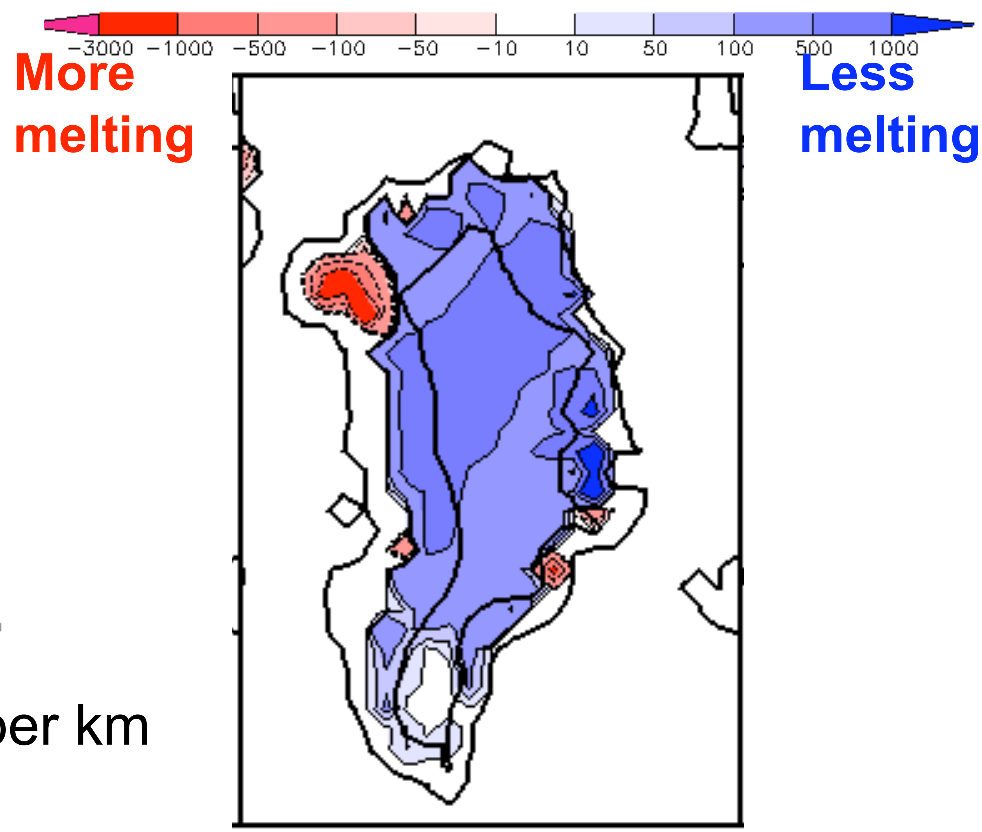
The temperature change with height is prescribed in off-line ("passive") simulations via constant lapse rate for downscaling

Volume [m SLE]



Lapse rate (downscaling) is 6.5°C per km

Melting anomaly [mm/yr] due to interactive ice sheet



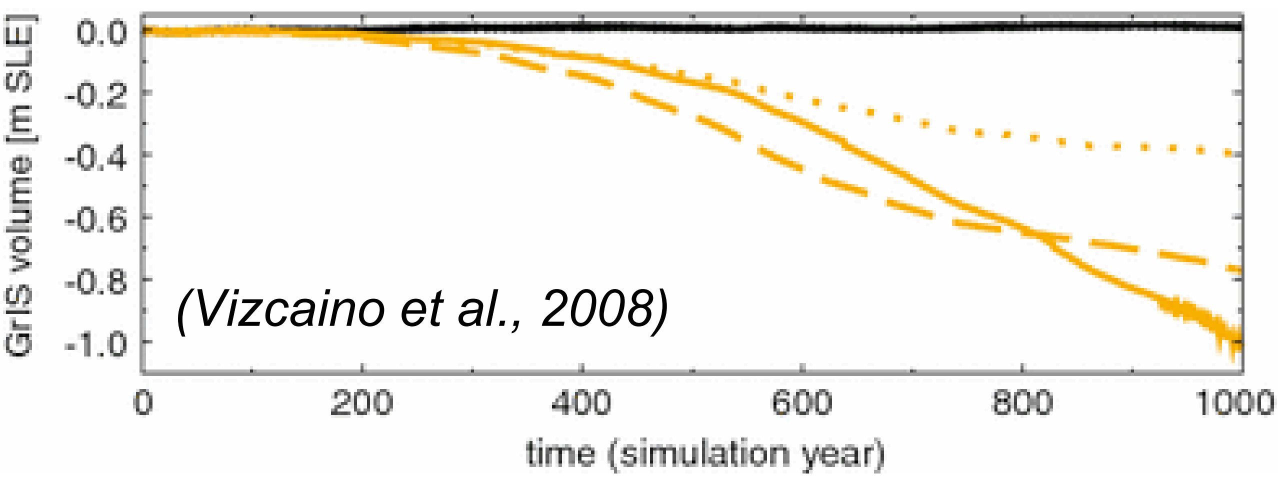
This effect is also a problem in interactive simulations, because of the need of downscaling

Changing topographic gradients and melting

Increased melting => lowers ablation zone => increased topogr.gradient => faster flow => ice thickens in ablation zone => less melting
ice thins in accumulation zone => melting area extends towards interior

Negative feedback for melting at first, later positive
(Huybrechts and de Wolde, 1999; Vizcaino et al., 2008)

Volume change [m SLE] in 3xCO2 simulation



CTRL
3xCO2
dotted=fixed topography
dashed=fixed advection

Outline

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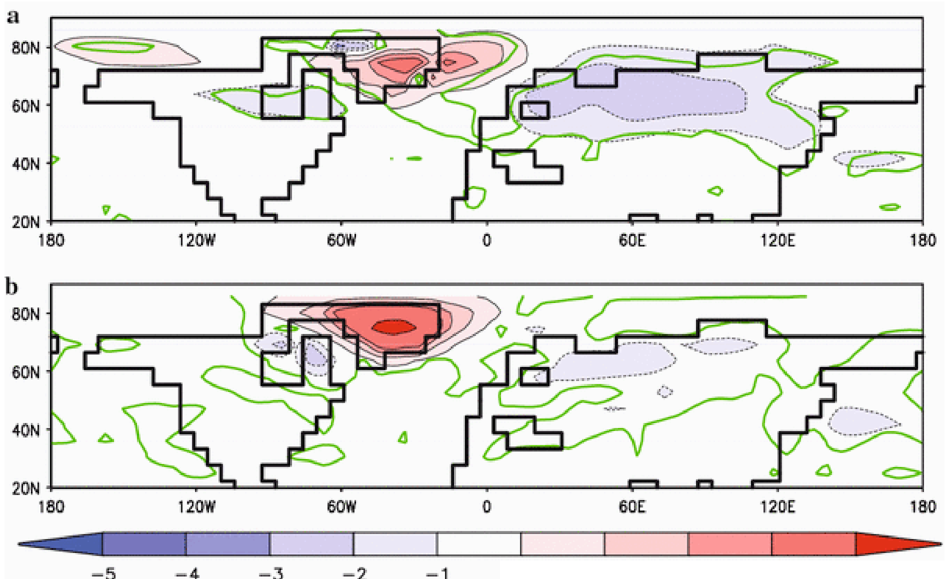
Effect of albedo change due to total deglaciation

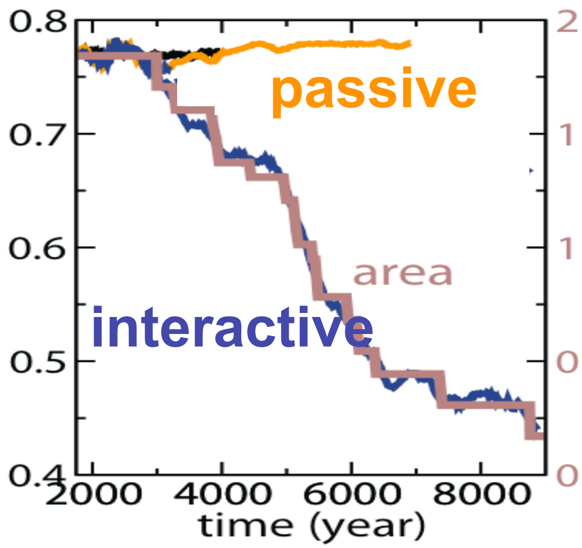
Strong albedo reduction increases summer temperatures over Greenland



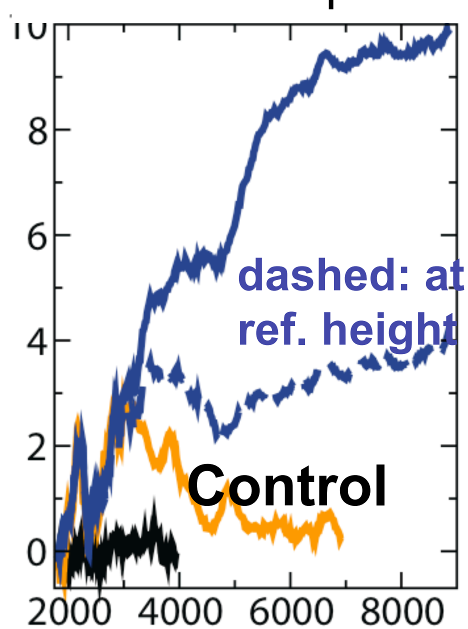
winter

summer

Summer albedo and area [mill km^2]



Summer temp. anomaly wrt pre-industrial



Delta T
from height

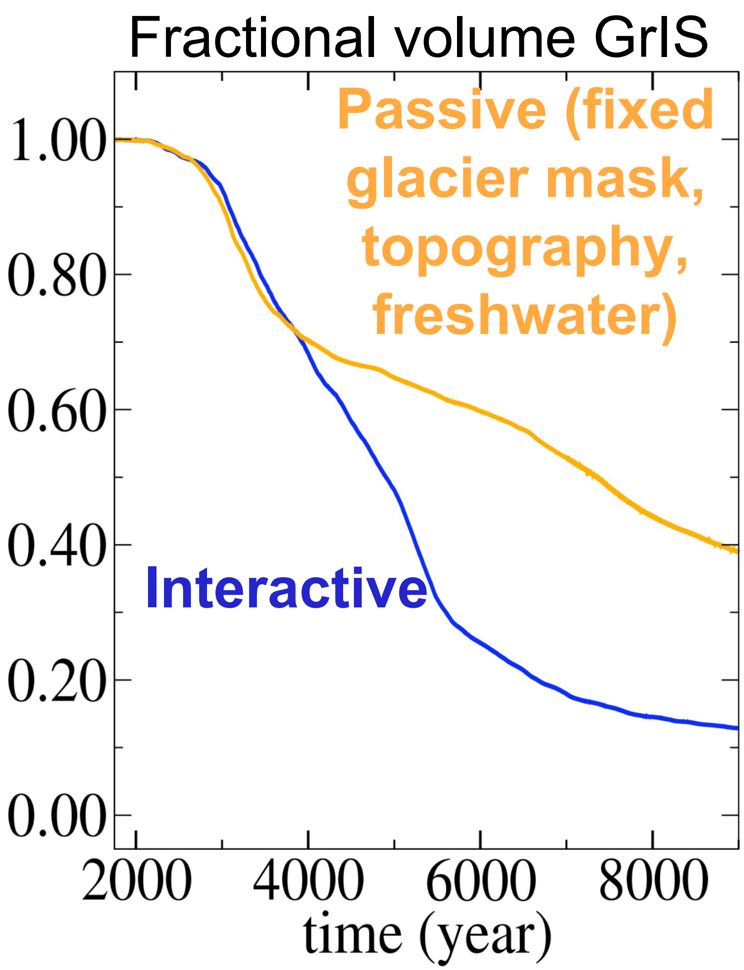
Delta T
from albedo

(Vizcaino et al., 2008)

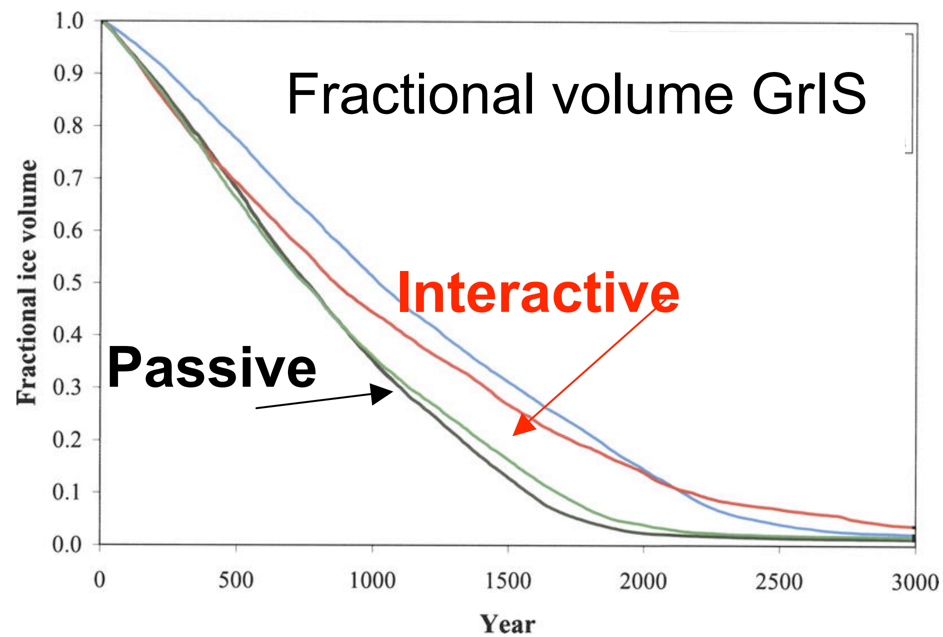
Effect of deglaciated areas on melting

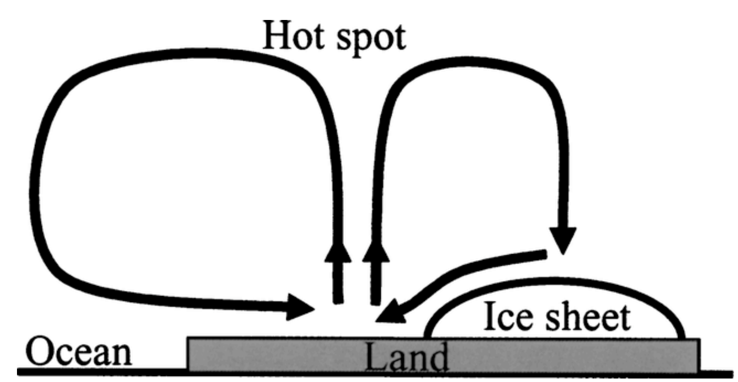
- Deglaciated areas warm due to reduced albedo: effect on deglaciation of ice sheet?

a) speed-up *(Vizcaino et al. 2008)*



b) slow-down *(Ridley et al. 2005)*



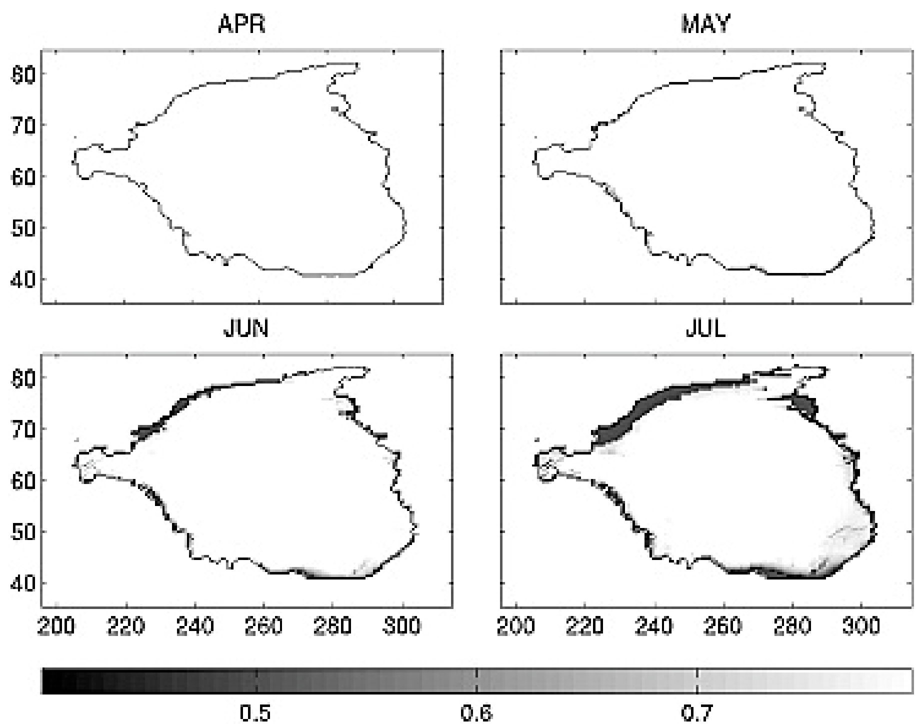


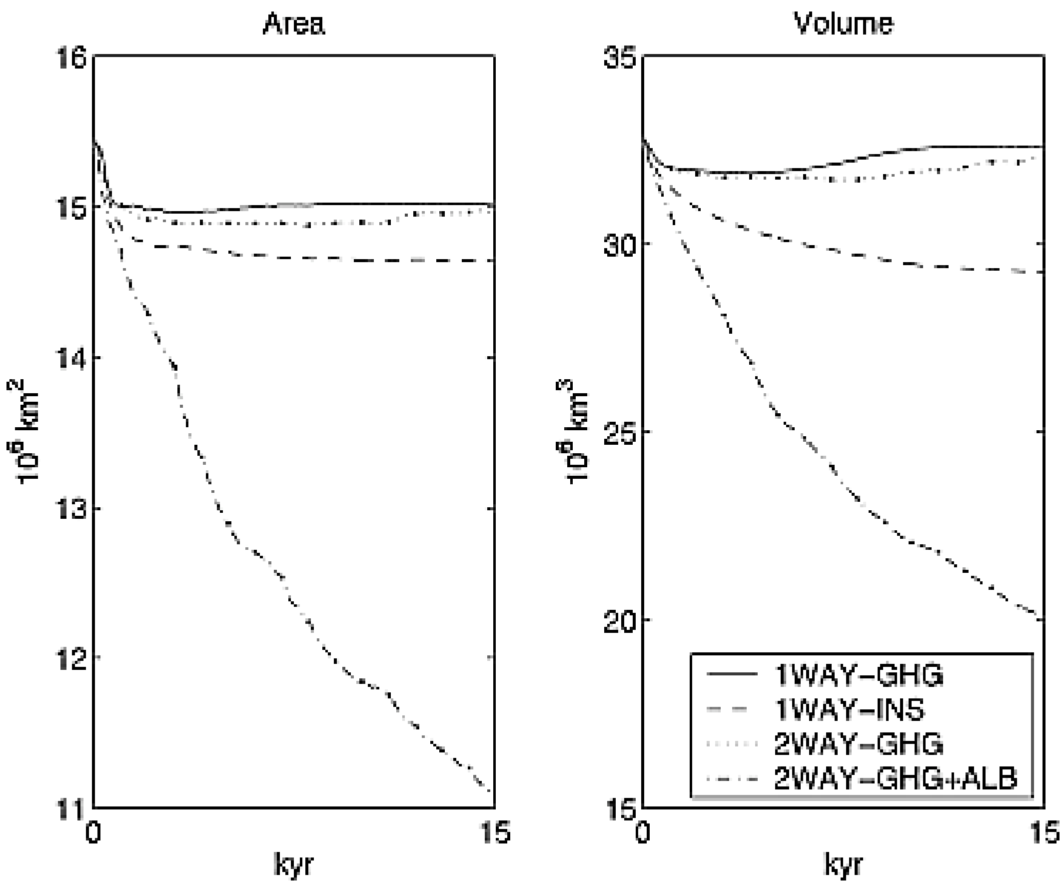
Effect of changing ice sheet albedo on melting

- Seasonally-varying albedos and bi-directional interaction between atmosphere and Laurentide ice sheet accelerate deglaciation (Pritchard et al. 2008)

Area and volume change

Seasonally changing albedo





Summary

- Freshwater fluxes from Greenland:
  - Diverse results: collapsing, weakening, no effect
  - Timing with regard to other forcings might be important
  - Collapse of MOC could cause regional cooling and reduced melting rates: negative feedback?
- Atmospheric circulation changes caused by Greenland deglaciation
  - More zonal flow in boreal high latitudes => cooling of Scandinavia
  - Intensification of storm track over Greenland
- Albedo effects:
  - Retreat of ice sheet: slowing-down or speeding-up deglaciation?
  - Variations in glaciated margins speeds-up deglaciation
- Thermodynamical effect of height change: magnitude depends on local conditions (e.g. melting surface)

Reversibility of deglaciation?

- If pCO_2 concentrations were reduced in the future (e.g. carbon sequestration), would the Greenland ice sheet recover?
  - After total deglaciation: (inception problem)

	yes	no
Crowley and Baum 1995		x
Calov et al. 2005		x
Toniazzo et al. 2004 (ipcc)		
Lunt et al. 2004	x	x
Vizcaino et al. 2008		x

Limitations of these studies: corrected forcing, resolution,

  - After partial deglaciation?

Implications for modeling

- Uncorrected atmospheric forcing instead of anomalies + climatology
  - Problem of corrected forcing: inconsistent climate regimes in ice sheet model and atmospheric model
- Calculation of surface mass balance energy balance instead of pdd
  - pdd overestimates ablation *(Bougamount et al. 2008)*
- Downscalling of atmospheric forcing via constant lapse rates might cause unrealistic results
  - E.g. Surface at melting point imposes a limit to increase in near-surface temperatures.
- Atmospheric resolution is critical for determining albedo
  - Solution: fractional land cover
- Modeling of albedo changes over ice surfaces:
  - In which model component? (atmosphere/ice sheet)
  - How?
  - Consistency of albedos in both models